CHAPTER 2: STATUS OF WINTER-RUN CHINOOK SALMON[1]

Introduction

Information on the status of winter-run chinook salmon is presented in four sections, as follows: 1) a description of the unique characteristics of winter-run chinook that qualify it as a distinct species segment or “species" under the ESA; 2) a more detailed description of the life history and biological requirements of winter-run chinook; 3) a description of the modification of freshwater habitats that have led to the decline of the population; and 4) a description of the historical decline of the population and its current probability of extinction.

Unique Species Characteristics

Like all species of Pacific salmon, chinook salmon are anadromous and semelparous; they originate in freshwater, grow to adulthood in the ocean, return to freshwater to spawn, and then die after spawning once. Within this broad life history pattern, chinook salmon have developed a diverse array of life history characteristics. These include: 1) variations in age at emigration; 2) length of residence in freshwater, estuarine, and ocean habitats; and 3) variations in age at spawning and spawning migration timing.

Chinook salmon in the Sacramento River are typically characterized as winter-, spring-, fall-run, or late-fall-run according to the time adults enter freshwater to begin their spawning migration. Accordingly, adult winter-run chinook salmon return to fresh water during the winter but delay spawning until the spring and summer. Juveniles spend about five to nine months in the river and estuary systems before entering the ocean. This life history pattern is unique and differentiates the winter-run chinook from other Sacramento River chinook runs and from all other populations within the range of chinook salmon (Hallock and Fisher 1985, Vogel 1985, California Department of Fish and Game 1989). This distinct life history also provided the basis for the population qualifying as a "species" under the ESA (National Marine Fisheries Service 1987).

The definition of a "species" according to the ESA is less restrictive than that for a taxonomic species and allows for the conservation of important populations within a species. Amended in 1978 (Public Law 95-632 (1978), 92 Stat. 3751), the ESA states that a species is any "distinct population segment of any species of vertebrate fish or wildlife which interbreeds when

[1] This chapter (2) provides a summary of the present status of the Sacramento River winter-run chinook salmon.

mature". Based on this definition, the winter-run chinook population is considered a "species" because it is reproductively isolated from the other Sacramento River chinook populations due to its distinct timing of upstream migration and spring/summer spawning, and because it possesses a variety of life history and phenotypic traits unique to the species (National Marine Fisheries Service 1987, 1992). Although a large study of genetically determined protein or allozyme variation did not reveal differences between the winter-run chinook and other chinook populations from California's Central Valley (Bartley et al. 1992), subsequent studies of DNA sequences, from both the mitochondrial (Nielsen et al. 1994a) and nuclear genomes (Banks et al. 1995), have provided supportive evidence for the genetic divergence and reproductive isolation of the winter-run chinook salmon.

In addition to their unique life history patterns, the behavior of winter-run chinook adults as they return to spawn further differentiates the population. Adults enter freshwater in an immature reproductive state similar to spring-run chinook, but winter-run chinook move upstream much more quickly and then hold in the cool waters below Keswick Dam for an extended period before spawning (Moyle et al. 1989). Winter-run adults also mature primarily as 2- and 3-year-olds (25%: 2-year-olds, 67%: 3-year-olds, 8%: 4-year-olds), whereas fall and late-fall-run chinook are mainly 3- and 4-year-olds (Hallock and Fisher 1985, Fisher 1994).

The habitat characteristics in areas where winter-run adults historically spawned are also distinctive suggesting unique adaptations by the population. Prior to construction of Shasta Dam, winter-run chinook spawned in the headwaters of the McCloud, Pit, and Little Sacramento rivers and Hat Creek as did spring-run chinook salmon. However, Scofield (1900) reported that salmon arriving "earlier" than spring-run (presumably winter-run) ascended Pit River Falls and entered the Fall River while the succeeding spring-run chinook remained to spawn in the waters below. This implies that winter-run chinook, unlike the other runs, ascended to the highest portions of the headwaters, and into streams fed mainly by the flow of constant-temperature springs arising from the lavas around Mount Shasta and Mount Lassen (Slater 1963). These headwater areas probably provided winter-run chinook with the only available cool, stable temperatures for successful egg incubation over the summer (Slater 1963). Other cold, snow-melt streams would have been too variable for sustained production of salmon. The historical occupation of unique habitats, as well as distinct life history and phenotypic traits, represent adaptive differences that distinguish winter-run chinook as a distinct population segment.

Life History and Biological Requirements

The unique natural history of winter-run chinook is discussed below, reflecting our present knowledge of the population's migration timing and distribution by life stage. The fundamental biological requirements of winter-run chinook are also reviewed to provide background for later discussions in this plan on factors affecting the population and on needed recovery measures.

Life History

Adult Spawning Migration and Distribution. Sacramento River winter-run chinook salmon enter San Francisco Bay from November through June (Van Woert 1958, Hallock et al. 1957). Their migration past Red Bluff Diversion Dam (RBDD) at river mile (RM) 242 begins in mid-December and continues into early August. The majority of the run passes RBDD between January and May, with the peak in mid-March (Hallock and Fisher 1985). In general, winter-run chinook spawn in the area from Redding downstream to Tehama. However, the spawning distribution, as determined by aerial redd surveys, is somewhat dependent on both the operation of the gates at RBDD, river flow, and probably temperature.

Most spawning occurs in the third year of life (Hallock and Fisher 1985). Only one tagging study was conducted on wild winter-run chinook over three brood years, and found that 25% returned as 2-year olds, 67% returned as 3-year olds, and 8% returned as 4-year olds. Since virtually none of the returning 2-year olds are females, and assuming an overall sex ratio of 1:1, the percentages of males returning at ages 2, 3, and 4 are 50%, 44%, and 6%, respectively, while percentages of females are 0%, 89%, and 11%, respectively. The average fecundity is estimated as 3,800 eggs per female, from fish collected over 8 years at the Coleman National Fish Hatchery (Frank Fisher, pers. comm). The dependence of fecundity on age is not known.

Until 1984, several dozen to several hundred adult winter-run chinook salmon also returned annually to the upper Calaveras River, a tributary to the lower San Joaquin River, to spawn below New Hogan Dam (California Department of Fish and Game memo 1992). Spawning escapement estimates made in the 1970s ranged from a few fish to up to 1,000. Very few have been reported seen during the 1980s with the last documented sighting of adults in 1984 (California Department of Fish and Game memo 1984) and a single juvenile observed in 1987 (U.S. Fish and Wildlife Service memo 1989). This run represented the only self-sustaining population of winter-run chinook outside of the Sacramento drainage. Unfortunately, exceptionally low flows in the Calaveras River due to the 1987-1992 drought and irrigation diversions may have eliminated this population.

In addition, winter-run chinook may have historically occurred in Battle Creek. Trap and seine sampling data show that small, newly emerged fry were captured from mid-September through November, and were of lengths suggesting they were winter-run chinook (Rutter 1902). At present, however, winter-run chinook salmon are found only in the Sacramento River below Keswick Dam.

Timing of Spawning and Fry Emergence. Winter-run chinook spawn from late-April through mid-August with peak spawning activity in May and June. Fry emergence occurs from mid-June through mid-October. Once fry emerge, storm events may cause en masse emigration pulses.

Juvenile Emigration. The emigration of juvenile winter-run chinook from the upper Sacramento River is highly dependent on streamflow conditions and water type. Emigration past Red Bluff (RM 242) may begin in late July, generally peaks in September, and can continue until mid-March in drier years (Vogel and Marine 1991). They are found in the river reach above the confluence of Deer Creek (RM 220) from July through September, and their distribution spreads slowly downstream to Princeton (RM 164) between October and March (Johnson et al. 1992). Emigration past the Glenn-Colusa Irrigation District's (GCID) Hamilton City Pumping Plant at RM 206 may occur as early as mid-July and continue through April (HDR Engineering Inc. 1993, Green, unpublished data).

The peak emigration of winter-run chinook through the Delta generally occurs from January through April, but the range of emigration may extend from September up to June (Schaffter 1980, Messersmith 1966, California Department of Fish and Game 1989, California Department of Fish and Game memo 1993b, U.S. Fish and Wildlife Service 1992, U.S. Fish and Wildlife Service 1993, U.S. Fish and Wildlife Service 1994). Low to moderate numbers may occur as early as October or November, or later in May, depending upon water year type, precipitation and accretion to the Sacramento River, and river flows. Distinct emigration pulses appear to coincide with high precipitation and increased turbidity (Hood 1990). Juvenile chinook of winter-run size have also been collected in Montezuma Slough in November, following early fall storms in October (Pickard et al. 1982). Juvenile winter-run chinook seem to emigrate from the Delta to the ocean from January (possibly late-December) through June.

Scale analysis indicates that winter-run chinook smolts enter the ocean at an average fork length (FL) of about 118 mm, while fall-run smolts average about 85 mm FL (California Department of Fish and Game unpubl. data). Considering their time of emergence and growth rates, this length for saltwater entry supports the January through April period of peak emigration. This evidence suggests that winter-run juveniles reside in fresh and estuarine waters for 5 to 9 months prior to actively emigrating as smolts to the ocean. This period of in-river and Delta residence exceeds that of fall-run chinook salmon by 2 to 4 months.

Adult Ocean Distribution. At present, information on winter-run chinook ocean distribution is derived mainly from a tagging study conducted on 1967-71 broodyears. Because the data are derived from fisheries, they are biased in favor of locations where fisheries occur.

Approximately 720,000 juveniles from these brood years were seined from the Sacramento River at Red Bluff in September and October and fin-clipped at Coleman National

Fish Hatchery. Returns from these marked winter-run indicate that most winter-run salmon caught in the ocean are landed between Monterey and Fort Bragg. However, mark duplication of Trinity River Hatchery salmon during the same period made it difficult to tell if any winter-run were landed north of Fort Bragg (Hallock and Fisher 1985). Regardless of this, it is believed that winter-run chinook salmon, like all Central Valley chinook, remain localized primarily in California coastal waters.

Biological Requirements

Adult Upstream Migration and Spawning. Acceptable temperatures for adults migrating upstream range from 57° to 67°F. When winter-run chinook reach their spawning habitat, they are immature and need to stage for several months before spawning. Having ceased feeding upon entering freshwater, adults need to conserve energy for gamete production, mate selection, redd construction, and spawning and redd guarding. Cold-water refuges, such as deep pools, are likely important for energy conservation, as found with spring-run chinook which also mature over several months in freshwater (Berman and Quinn 1991). Generally, the maximum temperature for adults holding, while eggs are maturing, is about 59-60°F, but adults holding at 55-56°F have substantially better egg viability (Boles 1988, Hinz 1959). Staging areas for winter-run chinook are mostly available above Bend Bridge and below Keswick where deep pools are scattered within volcanic bedrock (F. Fisher, pers. comm.).

Chinook salmon spawning generally occurs in swift, relatively shallow riffles or along the edges of fast runs where there is an abundance of loose gravel. The females dig spawning redds in the gravel and deposit their eggs in several pockets. The eggs are fertilized by the male and buried in the gravel by the female. The adults die within a few days after spawning. Water percolates through the gravel and supplies oxygen to the developing embryos.

Salmon select spawning riffle areas within narrow ranges of water velocity and depth. The velocity determines the amount of water which will pass over the incubating eggs. In general, optimum spawning velocity is 1.5 feet per second (fps), but may range from 0.33-6.2 fps (Healey 1991). Depths under 6 inches can be physically prohibitive for spawning activities. Winter-run chinook appear to select deeper waters over seemingly suitable habitat in shallow waters. Observations from SCUBA surveys found that winter-run chinook spawned at depths ranging from 1-3 ft to 10-15 ft (J. Smith, pers. comm.). In Lake Redding, winter-run chinook have been observed spawning at depths exceeding 21 feet (California Department of Fish and Game 1993a).

For successful reproduction, chinook salmon require clean and loose gravel that will remain stable during incubation and emergence. In general, the substrate chosen by chinook salmon for spawning is composed mostly of gravels from 0.75-4.0 inches in diameter with smaller percentages of coarser and finer materials with no more than about 5% fines. Gravel is completely unsuitable when it has been cemented with clay and other fines, or when sediments settle out and cover eggs during the spawning and incubation period. Such deposited sediments can reduce percolation through the gravel and suffocate eggs or alevins.

Egg and Larvae Incubation. The minimum intra-gravel percolation rate to ensure good survival of incubating eggs and alevins will vary, depending on flow rate, water depth, and water quality. Under controlled conditions, survival rates of 97% and greater have been observed with a percolation rate of 0.001 ft/s (0.03 cm/s), whereas 60% survival was observed at a 0.0001 ft/s percolation rate (0.0042 cm/s) (Shelton 1955, Gangmark and Bakkala 1960). In general, percolation rate must be adequate to maintain oxygen delivery and remove metabolic wastes. Significant decreases in flow during the incubation period can result in reduced interstitial flow through the spawning gravel which can suffocate eggs and alevins. Oxygen requirements of developing eggs and sac fry or alevins will also increase with increasing temperature.

The preferred temperature for chinook salmon incubation is generally 52°F with lower and upper threshold temperature of 42°F and 56°F, respectively (Combs and Burrows 1957; Seymour 1956: as cited by Boles 1988). Daily average water temperatures of ≤56°F are generally suitable for maintaining inter-gravel water temperature, since redds are generally cooler and experience less diurnal fluctuation than the water column. Reduced egg viability and significant egg mortality occur at temperatures in excess of 57.5°F, with total mortality normally occurring at 62°F. Within the appropriate temperature range, eggs usually hatch in 40-60 days, and the young "sac fry" usually remain in the gravel for an additional 4-6 weeks until the yolk sac is completely absorbed. The rate of development is faster at higher water temperatures.

Fry Emergence and Juvenile Rearing. After emerging from redds, most chinook fry are dispersed to downstream areas, where they initially hide, possibly in the gravel. Small fry then appear in calm, shallow waters characterized by fine sediments and bank cover, in particular within back eddies, behind fallen trees, and near undercut tree roots. As juveniles increase in size, they gradually move to deeper and faster waters associated with coarser substrates either along the stream margin or farther out from shore (Chapman and Bjornn 1969, Lister and Genoe 1970; cited from Healey 1991).

As juveniles begin to actively move above the river and feed, they become more temperature tolerant. Temperature conditions optimal for chinook fry are slightly higher than for eggs and larvae, ranging from 53.6°F to 57.2°F, with maximum growth occurring at 55°F (Boles 1988, Seymore 1956). Optimal temperatures for fingerlings similarly range between 53°F and 57.5°F.

A minimum streamflow of 3,250 cfs is considered necessary for safe rearing and downstream passage, although flows of 5,000-5,500 cfs should provide more suitable rearing habitat (National Marine Fisheries Service 1993, U.S. Fish and Wildlife Service 1995). Rapid flow fluctuations are detrimental, causing stranding of juveniles particularly in side channels with narrow inverts and in nearshore areas with broad, flat gradients. Submerged cover and overhead cover provide shade and protection against predation. Submerged cover is afforded by large rocks, aquatic vegetation, logs and other natural structures. Overhead cover is provided by riparian vegetation, turbulent water, logs and undercut banks. Riparian vegetation within and above the water also provides substrate and nutrients which increases the productivity of aquatic and terrestrial invertebrates, an important food source for salmon.

Upon reaching the estuary, juvenile salmon forage in intertidal and shallow subtidal areas, specifically in marsh, mudflat, channel, slough or bay habitats. These habitats provide both a rich food supply and protective cover within shallow turbid waters (McDonald 1960, Dunford 1975; cited from Cannon 1981). The distribution of juvenile chinook changes tidally, with fry moving from tidal channels during flood tide to feed in near-shore marshes (Healey 1991, Levy and Northcote 1981, Levings 1982). Chinook fry scatter along the edges of marshes at the highest points reached by the tide, then with the receding tide, retreat into tidal channels that dissect marsh areas and retain water at low tide. Larger fry and smolts tend to congregate in surface waters of main and subsidiary sloughs channels and move into shallow subtidal areas to feed (Allen and Hassler 1986). There is little specific data on the behavior and use of juvenile winter-run chinook salmon in these estuarine habitats. Until more information is obtained, it is assumed that these habitats are important for winter-run chinook as research has demonstrated for other populations of salmon.

Optimal water temperatures for growth of juveniles in estuaries is 54-57°F (Brett 1952). Water temperatures reach 54°F by February in most years in Suisun and San Pablo Bays, while other Delta waters do not warm up to 54°F until March. However, high water temperatures in shallow bays may inhibit growth and affect the migratory behavior of juveniles. The specific cues triggering juveniles to migrate from the Sacramento-San Joaquin Estuary are not well understood, but water temperatures of 59°C and higher have been observed to induce migration in Northwest estuaries (Dunford 1975, Reimers 1973: cited from Cannon 1981).

Finally, freshwater inflow to the estuary is important for providing beneficial environmental conditions and food production for salmon outmigration. High river flows in the winter and spring enable juveniles to actively migrate to the estuary, while positive outflow in the Delta improves juvenile survival and migration to the ocean. High freshwater flows may also stimulate and sustain production of food.

Historic Habitat Alteration

A wide range of factors are likely responsible for the decline of the Sacramento River winter-run chinook salmon. Water diversions and other unscreened ditches have been recognized as depleting chinook populations as far back as the late 1800s (California Fish and Game Commission 1890). Clark (1929) also reported the loss of juvenile salmon to "the intakes of irrigation and power plant ditches", with one of the larger water diverters being the Central Canal and Irrigation Company (CCIC). The CCIC began diverting water, unscreened, from the Sacramento River in 1906. Subsequently in 1920, the Glenn-Colusa Irrigation District (GCID) purchased the existing CCIC irrigation system, and expanded the canal system and increased pumping capacity from 900 cfs to 1,700 cfs. GCID eventually became the largest water diverter on the Sacramento River (Hallock and Van Woert 1959), with a pumping capacity of 2,600 cfs. Their pumps were unscreened and drew small fish into the canal (Clark 1929) until 1935, when screens were installed by mandate from CDFG. However within 3 years, these screens (¼ inch by 1 inch steel bars) were damaged during flood flows and rendered ineffective, but remained in place until the 1970s.

Many small dams were also built in the Sacramento River watershed during the early part of this century which reduced the reproductive potential of winter-run chinook. First, Battle Creek was developed for hydropower in 1903. In 1917, the Anderson Cottonwood Irrigation Diversion (ACID) dam was installed seasonally on the Sacramento River at Redding. The ACID dam was built without fish ladders, thereby blocking virtually all salmon from migrating to headwater spawning streams between April and August (McGregor 1922). The ACID dam created such a significant barrier that salmon runs were considered nearly exterminated in the rivers upstream from the dam (Clark 1929). In 1927, a poorly designed ladder was constructed, but flows in the ladder (60 cfs) were too low to fully attract and pass upstream-migrating fish (Resources Agency 1989). Salmon could return to the upper watershed, but their passage was still impeded and their numbers considerably reduced (Clark 1929). Substantially lower nuclear DNA variation in the contemporary winter-run chinook population relative to fall or late-fall run chinook in the upper Sacramento River (Banks et al. 1995) may well reflect a reduction of the winter-run chinook's genetically effective population size during the period when the ACID dam blocked upstream passage of spawning adults.

Subsequently, numerous permanent dams were built in the Pit River watershed for hydropower (Pit #1 Dam in 1922; Pit #3 Dam between 1923-1925; and Pit #4 Dam in 1927). A minimum of 21 miles of winter-run chinook spawning habitat was lost due to these dams, but perhaps more than 71 miles were lost depending on the extent of the historic winter-run chinook spawning range, which is unknown.

Water quality was also a problem in the Sacramento River as early as the 1900s. Acid drainage from mining activities in the Spring Creek watershed contaminated the upper Sacramento River in the early 1900s (U.S. Fish and Wildlife Service 1987). Adult salmon were also reportedly killed from the drainage of rice fields (Clark 1929). In the 1940s, the widespread application of fertilizers, soil amendments, herbicides, and pesticides began further degrading water quality.

In the Bay-Delta, urban and industrial developments affected water quality as early as 1890, when excessive sewage discharge created anoxic, contaminated conditions (Skinner 1962). Major oil refineries were built beginning in 1896, which frequently released oily discharges because refining processes were poor (Union Oil facility--1896, Chevron--1902, Tosco--1912, Shell--1915, and later, Pacific--1966 and Exxon--1968) (Skinner 1962). Heavy shipping traffic also released excessive oil discharges, as did auto garages (estimated at 3,000 gallons of oil per day in 1925)(Skinner 1962). Pollution loading from urban and industrial discharge increased in proportion to the human population until the 1950s, and was considered significant factor to the overall decline of salmon at the time (Skinner 1962). Water quality started improving in the 1950s, when controls began to be imposed (Davis et al. 1991) .

These anthropogenic effects on winter-run chinook were compounded during this period with large scale environmental perturbations. One of the most severe droughts on record developed between 1928 and 1934 (Rozengurt et al. 1987) with dry conditions extending from as early as 1917 to 1937. Also, Mud Creek, a tributary to the McCloud River, rolled with glacial debris from Mount Shasta in 1924 depositing about 10 million cubic yards of sediment between the mouth of its canyon and the McCloud River.

The cumulative effects of habitat alteration from water development and increased municipal and industrial growth may have induced a dramatic decline in winter-run chinook during the 1920s. Evaluation of data from in-river gill-net landings at Rio Vista and San Francisco has provided population indices of winter-run chinook, for 1916 to 1951 (Figure II-1) (Fisher 1993; Brown 1993). Accordingly, winter-run chinook appeared to have increased from 1916 into the 1920s, but then dropped precipitously, coincident to various water development projects (ACID, Pit Dams, GCID). The population remained very low throughout the 1920s and into the 1930s, a period compounded by one of the most severe droughts on record from 1928 to 1934.

Construction of Shasta Dam

These drought conditions and the resulting water deficiencies in the San Joaquin Valley was one of the major incentives for development of the Central Valley Project and the subsequent

State Water Project (U.S. Department of Interior 1970). Another incentive was a large lawsuit between the Delta and upland water users over Delta salt water intrusion, which was dismissed on the assumption that the Central Valley Project would resolve the conflict (Basye 1981). In 1937, Congress authorized construction of the Central Valley Project, triggering the valley into the era of high dams and intensive water manipulation. Construction of the Shasta Dam began in 1938, and by May 1942, the dam complex completely blocked winter-run and other chinook populations from their upstream spawning grounds.

The spawning range of winter-run chinook was substantially reduced by Shasta Dam from about 100 linear miles (estimated habitat remaining in the upper watershed after hydropower development on the Pit River), to about 50 linear miles of available habitat below Shasta Dam, during years with the most favorable environmental conditions (Fisher, pers. comm.). Winter-run chinook were forced to spawn in the main stem of the Sacramento River, largely from Redding downstream to Tehama (Hallock and Fisher 1985).

In the years immediately following the closure of Shasta Dam, environmental conditions in the Sacramento River were so adverse that winter-run chinook reproductive success was probably poor to completely unsuccessful in the main stem river (Slater 1963). Water temperatures began to improve in 1944 but not until 1945 did temperatures improve to levels allowing successful reproduction. Oxygen deficient water, typical of new reservoirs, was also common in the initial dam releases. In addition, the effects of toxic runoff from Spring Creek mine tunnels increased since Shasta Dam releases were too low to dilute contaminants, resulting in heavy mortalities to adult salmon (Moffett 1949).

The overall, environmental effects of Shasta Dam on the Sacramento River were profound and included stabilizing the water temperatures and stream flow, and modifying the patterns of flow and water temperature. Water temperatures became lower in the summer and higher in the winter, and stream flow became lower in the winter and higher in the summer. Maximum monthly flow at Bend Bridge in February decreased from 24,760 cfs to 19,340 cfs, whereas minimum monthly flow increased from 4,381 cfs to 6,501 cfs (Table II-1). In addition, Shasta Dam acted as a settling basin which removed large quantities of river-borne silt and debris, thereby reducing water turbidity in releases at Shasta Dam.

Table II-1. Statistics of Flow Data (cfs) for Sacramento River at Bend Bridge for Water Years, 1892 - 1992.

Years	Maximum Mean Monthly	Minimum Mean Monthly	Highest Daily Mean	Lowest Daily Mean
1892 -1943	24,760 February	4,381 August	281,000 Feb 28, 1940	2,400 Aug 13, 1931
1946 -1962	19,340 February	6,501 October	125,000 Feb 19, 1958	3,640 Jan 31, 1949
1964 -1992	19,700 February	6,968 October	127,000 Jan 27, 1970	3,200 Oct 11, 1977

Delta Diversions

In 1948, the CVP began delivering water from the Delta through the Contra Costa Canal at Rock Slough (pumping capacity of 350 cfs) to provide water to municipalities and industries in Contra Costa County. Major water diversions began in 1951, when Sacramento River water was delivered to the Delta-Mendota Canal, at a capacity of 4,600 cfs (Erkkila et al. 1950). In 1951, the Delta Cross Channel was dredged on the Sacramento River at Walnut Grove, creating an opening to Snodgrass Slough and the lower reaches of the Mokelumne River, to direct an increased supply of Sacramento River water south across the Delta to the Tracy Pumping Plant (Department of Water Resources 1993).

Prior to initial pumping, fisheries studies were conducted to assess the potential effects of the Tracy Pumping Plant and Delta Cross Channel (Erkkila et al. 1950). Significant proportions of juvenile Sacramento River salmon were observed to naturally migrate into the Delta via Georgiana Slough, in direct proportion to the flow of water. Salmon then dispersed with Sacramento River water throughout the central and south Delta, with their seaward migration delayed. Juvenile chinook also moved through Three Mile Slough and Sherman Lake into the central Delta. Sacramento River salmon apparently did not immediately migrate seaward but remained in the San Joaquin Delta for varying periods of time.

With the initial Tracy Pumping Plant operations, water was exported primarily during the agricultural season, usually from April into early fall. The volume of water exported ranged from 0.1 to 1.6 MAF (for years 1957-1967), with the highest quantities typically pumped in the driest years (State Water Resources Control Board 1988). As early as 1953, exports were periodically so high that the net flow in the San Joaquin River was reversed (Ganssle and Kelley 1963). Dimensions in the Delta Cross Channel and Georgiana Slough were too small to supply a southerly flow sufficient to meet demand at the pumps, and water was drawn from the western Delta (at the confluence of the Sacramento and San Joaquin rivers), eastward up the San Joaquin River, and down Old and Middle Rivers towards the pumps. These net upstream flows (or reverse flows) in the lower San Joaquin River were typical from July through September, and often into October during the 1950s and early 1960s (Ganssle and Kelley 1963). Under these conditions, little or no San Joaquin River water reached the western Delta. Net upstream flows caused great concern for the survival of juvenile San Joaquin fall-run chinook salmon, but probably were of lesser concern for winter-run chinook because of the time in which they occurred.

In 1959, the State legislature passed the Burns-Porter Act authorizing the State Water Project (SWP). Its main components were the Harvey O. Banks Delta Pumping Plant with its intake channel and Clifton Court Forebay, the California Aqueduct, San Luis Reservoir, and Oroville Dam on the Feather River. The new SWP pumps had a pumping capacity of 6,300 cfs, more than doubling the existing potential to export water (Basye 1981). The SWP began delivering water in 1962, but total water exports did not substantially increase until 1967, when the SWP began to export water via the San Luis Reservoir storage unit and the California Aqueduct. In 1968, total annual water exports from the CVP and SWP projects climbed from an average of 1.4 MAF (1958 - 1967) prior to the SWP, to 2.5 MAF (1968). Exports continued to increase over the next 20 years reaching an annual average of 5.3 MAF (1985-87) (State Water Resources Control Board 1988). In addition to the summer and fall irrigation seasons, water became exported during the winter and spring to fill the San Luis Reservoir. Eventually, a second peak in pumping developed, typically between December and April, which encompassed the peak period of juvenile winter-run chinook emigration through the Delta (January through April) (California Department of Fish and Game 1989).

Sacramento River Management and Alteration

During the first two decades following the completion of Shasta Dam, operations of the dam provided in-river conditions that sustained the winter-run chinook population. Abundance estimates for winter-run chinook salmon in the 1960s ranged from a high of 125,000 in 1962 to allow of 49,000 in 1965 (Figure II-1) (Fisher 1993; Brown 1993).[2] In the subsequent two

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[2] Abundance estimates were made using sportfish landings from angler surveys along the Sacramento River between Knights Landing and Keswick Dam, during the months of January, February, and March. Total landings from March were used because winter-run chinook occur in peak abundance in this section of the river at this time. The proportion of winter-run chinook in the sport catch was calculated using the estimated total sport catch from 1968-1975, relative to winter-run chinook population estimates made at RBDD. These proportions were then applied to the sport catch data from the 1962-1966 period. In-river sport catch ranged from 7% to 14% of the winter-run chinook population, and an average of 8.8% was used to calculate abundance (Fisher 1993; Brown 1993).

decades, however, operations of the dam failed to consistently supply cold water to the river, resulting in poor spawning and rearing conditions (Hallock and Rectenwald 1990). Typically, beginning in late spring, large releases were made from the Shasta-Trinity Division of the CVP (Figure II-2), which provided cool water temperatures through early summer (U.S. Fish and Wildlife Service 1987). With continued high releases, however, water elevations in Shasta Reservoir dropped to levels in the late summer and early fall where the intakes could only access warm water (Figure II- 3), thereby causing water temperatures to warm in the Sacramento River above the maximum 56°F temperature needed for successful incubation (Figure II-4). As water demands grew in the Central Valley, the magnitude and frequency of such reservoir drawdowns increased, and was intensified during dry water years. Losses of winter-run chinook due to high water temperatures have been considered significant during years of low reservoir storage (Resources Agency 1989), such as with the 1976 drought.

Low reservoir elevations also made it more difficult to control toxic runoff from Iron Mountain Mine in the Spring Creek watershed. In 1963, mining operations were discontinued and a debris dam built to trap toxic runoff. However, metal-laden waters continued to spill over the debris dam and into the Keswick Reservoir during high winter flows. Releases from Shasta Dam were made to dilute the contaminants released from Keswick Reservoir, but these releases were minimal to low during years with poor carryover storage in Shasta Reservoir (U.S. Fish and Wildlife Service 1987). Acute and chronic toxicity resulted in the upper 30 miles of the Sacramento River, with documented fish losses in 1964, 1967, 1969, and 1978 (Resources Agency 1989).

Operations of the Shasta/Keswick dams also resulted in large fluctuations in water releases from Keswick Dam (ramping). Flow releases from Keswick Dam were often reduced at rapid rates, sometimes exceeding 8,000 cfs within a few hours, to accommodate adjustments of the ACID dam (Reynolds et al. 1990). Significant flow fluctuations in the spring disrupted the spawning of winter-run chinook adults, and reduced water flow to redds or completely exposed redds, suffocating eggs and alevins (Vogel 1985). In the fall, high ramping rates caused stranding and loss of winter-run chinook fry in side channels and in broad, near-shore areas with flat gradients (Reynolds et al. 1990).

Red Bluff Diversion Dam (RBDD)

In 1967, the construction and operation of the RBDD, about sixty miles below Keswick Dam, created another significant impediment to winter-run chinook migration and survival. RBDD was designed to allow fish passage through a system of ladders and bypass pipes, and to mitigate for the loss of spawning habitat with the use of the Tehama-Colusa Fish Facility, an artificial spawning canal.

Although these ladders enabled biologists to make more accurate estimates of run-sizes, the fish ladders were ineffective, impairing the passage of adult winter-run chinook by delaying or blocking their migration (Hallock 1983, U.S. Fish and Wildlife Service 1988). Adults blocked by the dam were forced to spawn downstream where river temperatures were frequently too high for incubating eggs to survive during the summer months. Adults delayed in attempting to pass RBDD suffered physiological stress associated with the delay and their repeated attempts to pass the dam, thereby reducing their energy reserves for production of viable eggs and spawning. RBDD also impaired the downstream migration of juveniles, entrained juveniles in canals, and increased predation on juveniles. In addition, the Tehama-Colusa spawning channels were unsuccessful in producing salmon and were discontinued in 1986.

River and Ocean Harvest

Native American Harvest

Before the European settlement, chinook salmon were harvested by Native Americans such as the Wintuan-speaking Patwin, Nomlaki and Wintu groups living along the Sacramento River from the Delta to its headwaters. The level of harvest is not known, but substantial catches are believed to have occurred, on par with the commercial fisheries that followed (McEvoy 1986). McEvoy (1986) surmised that these Native Americans had developed and maintained a productive fishery that was sustainable over the long term. Winter-run chinook were also likely harvested by the Wintu people living along the Pit and McCloud Rivers. When Livingston Stone first explored the headwaters of the Sacramento River, he found Wintu people spearing ripe salmon at the site on the McCloud River where he would later build Baird hatchery (Stone 1883).

In-river commercial harvest

The first known commercial salmon fishing began about 1850, using gillnets and seines in the Sacramento and San Joaquin rivers and in parts of Suisun and San Pablo Bays. In 1864, G.W. and William Hume and Andrews S. Hapgood began the first salmon cannery on the Pacific coast at Washington (Broderick) on the banks of the Sacramento River. The canning industry grew rapidly reaching its peak in 1881, with 21 canneries operating along the river and Bay.

Winter-run chinook were likely harvested in the gill-net fishery, supporting an early season on the Sacramento River at Rio Vista. Records of monthly shipments of fresh salmon were reported for 1872 from Rio Vista (Stone 1876). The proportion of landings (in pounds) made at the port for January, February and one-half of March have been calculated and applied to total Delta landings to estimate winter-run chinook catches (Fisher 1993). Principally, winter-run chinook were migrating in the Delta during this period. Some late fall-run and spring-run chinook were also landed, but they cannot be separated from winter-run chinook in the landing records.

Assuming winter-run chinook weighed 11 pounds per fish (Stone 1874), winter-run chinook would have composed about 11.7% of the total landings by weight at that site. If winter-run chinook composed 11.7% of the total in-river commercial harvest at all locations (4 million pounds) (Skinner 1962), then an estimated 468,000 pounds of winter-run chinook were landed in 1872 (or about 42,600 fish) (Figure II-5).

Further data reporting monthly landings were scattered in these early fishery records, making it difficult to assess trends in winter-run chinook landings. Annual landings, however, were recorded for Sacramento River salmon, perhaps inferring the harvest pressure on winter-run chinook (Figure II-6). From 1874 to 1880, commercial landings increased markedly from 4 million pounds to nearly 11 million pounds (Skinner 1962). In 1881 and 1882, monthly landings were again reported, indicating large catches of winter-run chinook, about 640,000 pounds (or about 58,200 fish) for each year. Annual catch levels of salmon remained high (9 million pounds) until 1884, when the commercial fishery collapsed. Central Valley salmon were likely unable to sustain both the heavy harvest imposed from the operation of 21 canneries, and the degraded habitat conditions from mining and other anthropogenic developments. Drought conditions were not evident at this time (Earle and Fritz 1986).

In-river harvest rebounded briefly beginning in 1887 (3.6 million pounds), reaching 6.5 million pounds by 1889, but subsequently dropped to 2 million pounds by 1891. Monthly landings were again recorded from 1893 to 1898, suggesting substantial harvest rates of winter-run chinook between 500,000 to 600,000 pounds (or about 40,000-60,000 fish).

Another increase in annual commercial salmon landings followed in the early 1900s with a record catch of 10 million pounds in 1910, but was succeeded by a tremendous drop with the lowest catch ever of 45,600 pounds landed in 1913. By 1915, harvest was up again with 3.5 million pounds landed. Monthly gill-net landings were consistently recorded beginning in 1916, allowing annual estimates of in-river harvest of winter-run chinook through the 1950s. Catch levels of winter-run chinook appeared much lower in the early part of the 20th century than previously, ranging from 120,000 pounds (about 11,000 fish) landed in the winter of 1916, to 200,000 (about 13,600 fish) in 1918 (Figure II-5).

Advent of commercial ocean fishery

About this time, commercial ocean trolling for salmon came into prominence. Originally developed by sport fishermen in Monterey as early as 1893, commercial ocean trolling began expanding to the rest of California about 1914, and increased rapidly between 1916 and 1919, with the exploitation of ocean fisheries north of Point Reyes and Bodega Bay (Clark 1929).

Ocean harvests were initially quite high (5-6 million pounds landed), while comparable catches were also made in the Sacramento River (3.5-6 million pounds). As the level of ocean trolling continued to increase, however, Sacramento River catches conspicuously dropped (Figure II-7) (Clark 1929). By 1919, the in-river canneries were legislatively abolished, and by 1926, the Sacramento River harvest fell to about 1 million pounds. In-river catches of winter-run chinook also dropped (30,000 pounds or about 2,700 fish in 1926), and remained low throughout the 1930s (Figure II-5).

Ocean harvest also fell during the 1920s and 1930s (from 6 to 3-4 million pounds), but remained higher than in-river harvest (California Department of Fish and Game 1971). The last substantial in-river harvest occurred in 1946 with 6.5 million pounds of salmon landed, including an estimated 280,000 pounds (about 25,500 fish) of winter-run chinook. In 1951, netting became prohibited in most of the Sacramento-San Joaquin River system above Pittsburg, and all commercial salmon fishing inside the Golden Gate was banned in 1957, a year with the second lowest river catch of salmon on record (321,824 pounds). Thereafter, the ocean troll fishery was the only legal commercial salmon fishery in California.

Ocean commercial catch of California stocks has varied from 3.5 to 8 million pounds between the late 1950s and 1990s (Figure II-7). However, the proportion of winter-run chinook in these catches is not known due to a lack of tagging studies. A tagging study was conducted in the late 1960s and early 1970s, which indicated a commercial ocean impact rate of about 9% on winter-run chinook (California Department of Fish and Game 1989).

Sport Fishery

Little data on the ocean sport fishery is available prior to 1940. Early party boat records of salmon catches show an increase from 5,000 pounds landed in 1947 (includes both chinook and coho for ocean and San Francisco Bay areas) to about 100,000 by 1956 (Frey 1971). Subsequently, lower catches were made (30,000-50,000 pounds landed), but increased again in the early 1960s (87,000 pounds landed in 1962). Records of statewide recreational ocean harvest of chinook salmon are available since 1962, indicating catches between 60,000 and 200,000 chinook throughout the 1960s, 1970s, 1980s and 1990s (Figure II-8) (Pacific Fisheries Management Council 1993). The proportion of winter-run chinook caught in these landings, as in the commercial landings, is not known due to lack of tagging studies. However, an impact rate of 26% was indicated for winter-run chinook through the recreational ocean fishery during the late 1960s and early 1970s (California Department of Fish and Game 1989).

Quantitative data on inland sport harvest of adult winter-run chinook are available since 1967. CDFG compiled sport harvest data for winter-run chinook in the Sacramento River as far downstream as Carquinez. The upmigration of winter-run chinook supported a substantial inland sport fish with as many as 11,000 fish caught in 1969 (Figure II-9). Catch levels dropped throughout the 1970s, and only 107 fish were landed in 1979. Harvest remained low throughout the 1980s until it was prohibited in 1988 during the upmigration and spawning period of winter-run chinook.

Summary of Fishery Impacts

Although the data are limited, it appears that winter-run chinook were able to sustain a substantial amount of harvest pressure during the 19th century and the first half of the twentieth century. Harvest has not been considered a leading factor in the demise of winter-run chinook as ocean harvest rates remained relatively stable throughout most of the period of the population's decline in the late 1970s and 1980s. However, substantial commercial and recreational ocean harvest in 1988 may have contributed to the decline in the 1989 winter-run chinook year class.

Decline of Population and Current Status

The long-term trend in abundance of the Sacramento River winter-run chinook salmon can be examined based on annual counts of the number of spawners passing RBDD. The estimated run size of winter-run chinook passing over the RBDD ladders averaged about 86,000 adults in 1967-1969, but decline to only about 2,000 adults by 1987-1989 (Table II-2). Since that time, the population has declined to lower levels. Based on the long-term trend data, the abundance of winter-run chinook has been declining geometrically (Figure II-10). This observation suggests that the decline of the population has been caused by low survival rather than the loss of necessary habitat (e.g., spawning grounds). If habitat loss were responsible for the decline, one would expect the population size to have declined precipitously rather than geometrically as has been observed (Figure II-11).

We have a reasonably certain estimate of total survival from spawner to spawner. The available data suggest the probability of winter-run chinook salmon going extinct in the near future is 1.0 (i.e., it will go extinct with certainty) if survival does not improve or remains the same as it has over the period that data on run size were collected (1967-1994). The rationale for this conclusion is contained in the chapter on extinction modeling (Chapter 4), but it is important to note that it only applies to the conditions which existed over the period during which data were gathered (1967-1994). Accordingly, it does not reflect the possible beneficial effects of recent improvements in habitat and water management. Unfortunately, there are only a few years of new escapement data available since recent habitat improvements have been made. These data are still too few and too uncertain to assess whether or not the population is continuing to decline, has stablized, or has begun to increase once again.

Summary

The decline of winter-run chinook can be traced to the loss of spawning habitat, dams and diversion, pollution, reductions in Sacramento River flow, and natural environmental variability. While the specific impacts of these various factors on winter-run chinook abundance are difficult to identify, it appears that the population declined both in numbers and in genetically effective size in the 1920s, coincident with the installation of dams on the Pit River and Sacramento River, other water diversions, and drought conditions. The population probably began rebounding in the late 1930s as cooler, wetter conditions developed and continued increasing after construction of Shasta Dam was completed, until the early 1970s when a strong downward trend again began.

The adult progeny from the broodyears 1968 through 1972 (returning to spawn in 1971 through 1975 respectively) all experienced sharp population declines. The timing of this decline roughly corresponds to the period of inadequate water temperature conditions in the upper Sacramento River, initial operations of RBDD, and increased water exports from the Delta. In addition, this decline occurred during a period of relatively productive ocean conditions and stable ocean harvest levels, and precedes the trend in poor ocean production conditions which began in 1976. This further substantiates the argument that the decline of the winter-run chinook population has been largely due to inland habitat factors, as opposed to ocean conditions. Cannon (1991) reported a similar decline in spawner-recruitment for fall-run chinook beginning in 1967, and attributed it to operation of RBDD, and the SWP export operations in the Delta.

Finally, the winter-run chinook population dropped to its present low levels, presumably due to continued poor habitat conditions, exacerbated by drought and strong El Niño conditions. The 1976-77 drought severely reduced the size of two consecutive cohorts leaving the 1978 brood as the only large spawning cohort (Table II-2). Subsequently, the strong El Niño event during 1982-83 likely contributed to the decline of this last strong cohort . Persistent poor habitat and drought conditions during the late 1980s and early 1990s lead to a further, order of magnitude decline in the population precipitating the listing of winter-run chinook under the Endangered Species Act.

Table II-2. Annual Estimated Winter-run Chinook Salmon Run-size at Red Bluff Diversion Dam, 1967 through 1995.

Year	Sacramento Winter-run Chinook Salmon Run-size			
	grilse [1/]	percent grilse	adults [2/]	total
1967	24,985	43.6%	32,321	57,306
1968	10,299	12.2%	74,115	84,414
1969	8,953	7.6%	108,855	117,808
1970	8,324	20.6%	32,085	40,409
1971	20,864	39.3%	32,225	53,089
1972	8,541	23%	28,592	37,133
1973	4,623	19.2%	19,456	24,079
1974	3,788	17.3%	18,109	21,897
1975	7,498	32%	15,932	23,430
1976	8,634	24.6%	26,462	35,096
1977	2,186	12.7%	15,028	17,214
1978	1,193	4.8%	23,669	24,862
1979	113	4.8%	2,251	2,364
1980	1,072	92.7%	84	1,156
1981	1,744	8.7%	18,297	20,041
1982	270	21.7%	972	1,242
1983	392	21.4%	1,439	1,831
1984	1,869	70.2%	794	2,663
1985	329	8.3%	3,633	3,962
1986	451	18.3%	2,013	2,464
1987	236	11.8%	1,761	1,997
1988	708	33.8%	1,386	2,094
1989	53	10%	480	533
1990	16	3.7%	425	441
1991	57	30.3%	134	191
1992	58	4.9%	1,122	1,180
1993	74	21.6%	267	341
1994	36	19.1%	153	189
1995	65	4.8%	1,296	1,361
1996	423	45%	517	940

[1/]. Fish of ages 2 or less are categorized as grilse and are typically males.
[2/]. Fish greater than age 2 are categorized as adults.

Figure II-1. Estimated winter-run chinook population indices for various years between 1872 and 1996, using three sources of information: (1) available data for Sacramento River gill-net landings from 1872 to 1950; (2) creel census data from 1962 to 1966; and (3) adult counts at the Red Bluff Diversion Dam from 1967 to 1996.

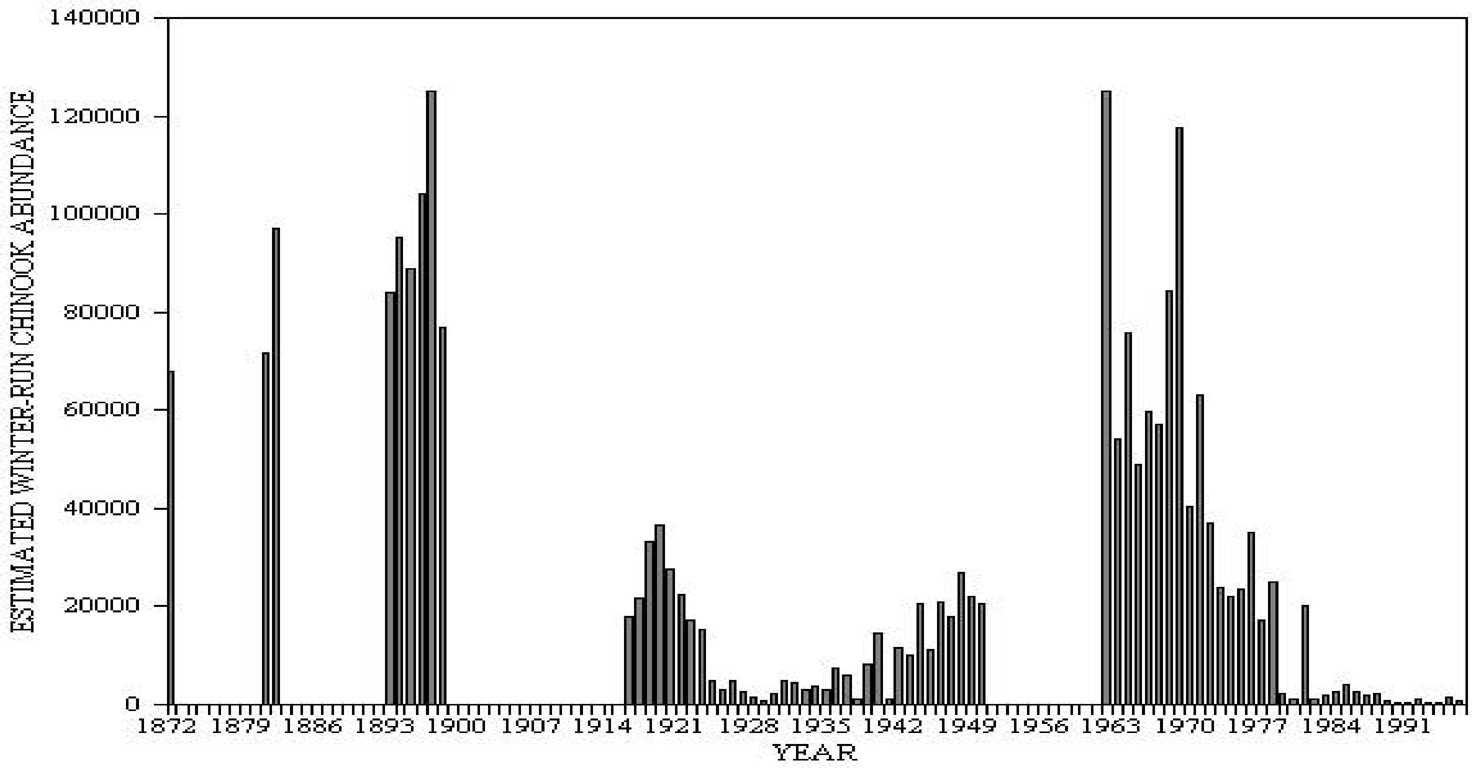


Figure II-2. Average monthly flow of Keswick Dam releases from 1938 to 1987.

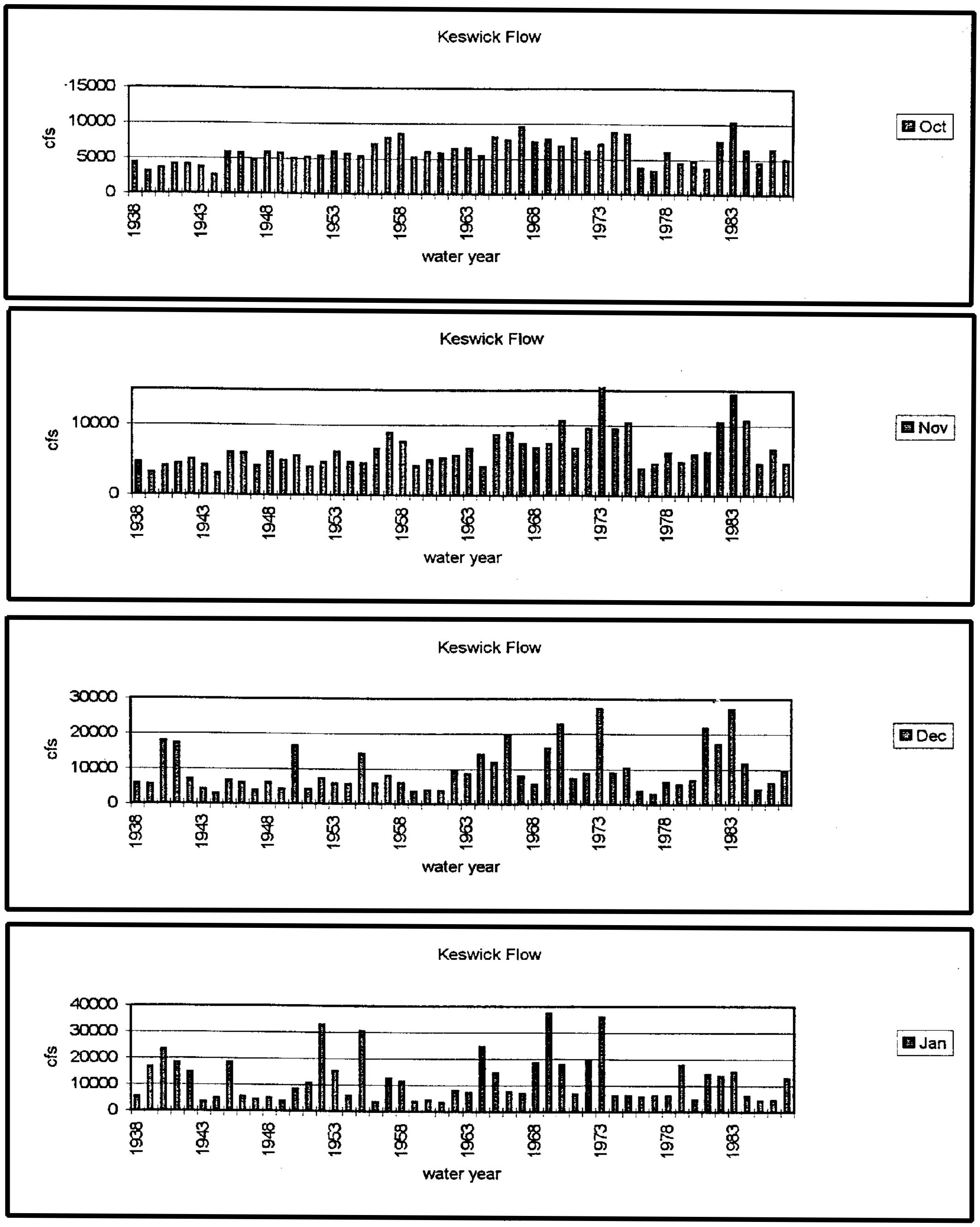


Figure II-2 continued. Average monthly flow of Keswick Dam releases from 1938 to 1987.

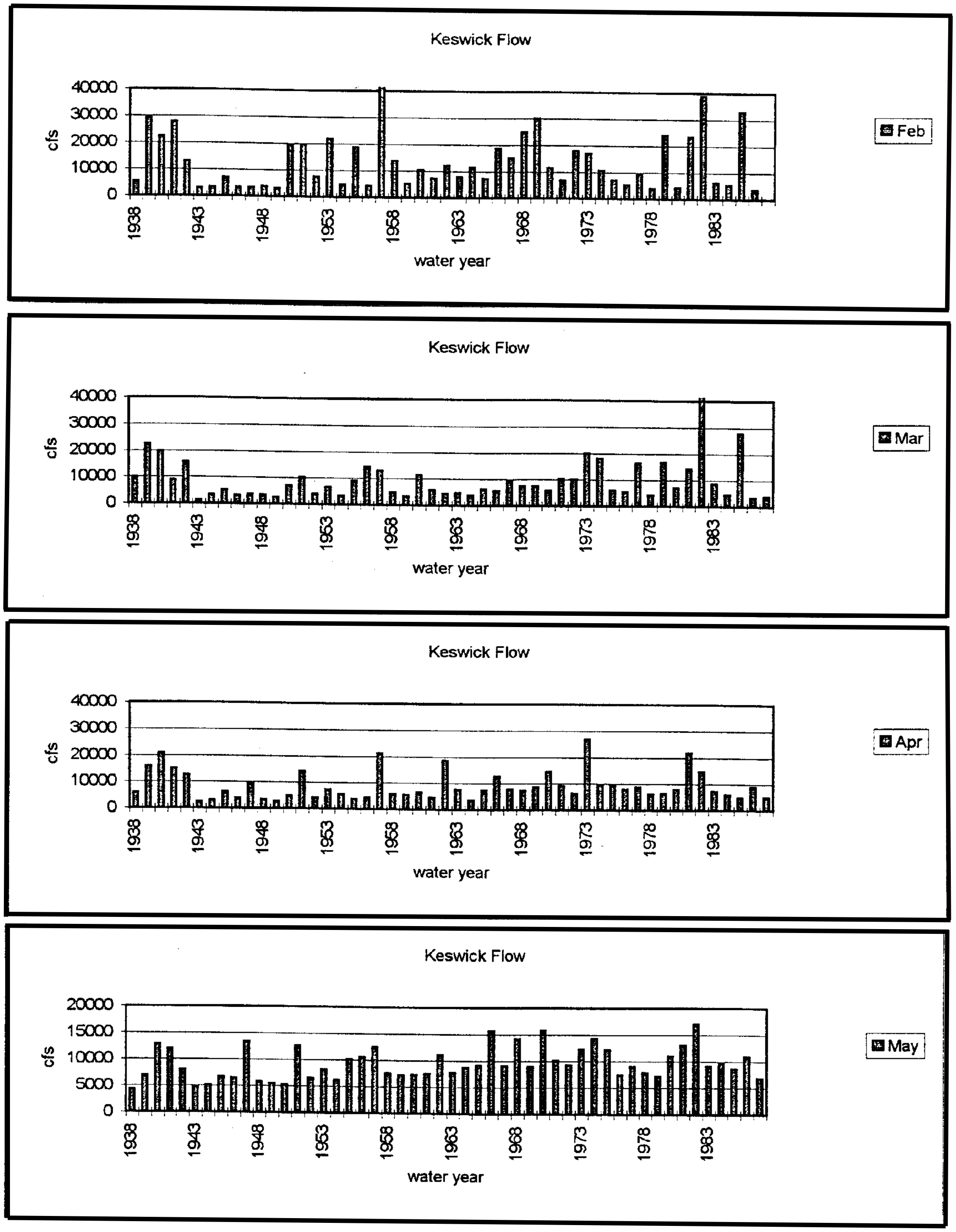
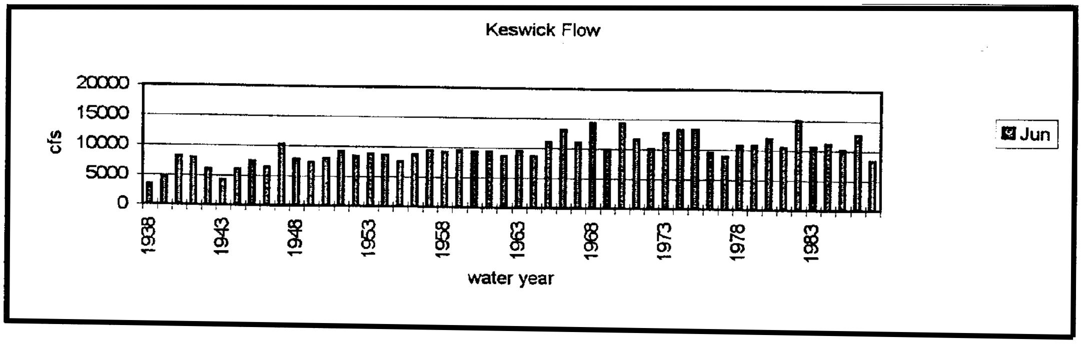
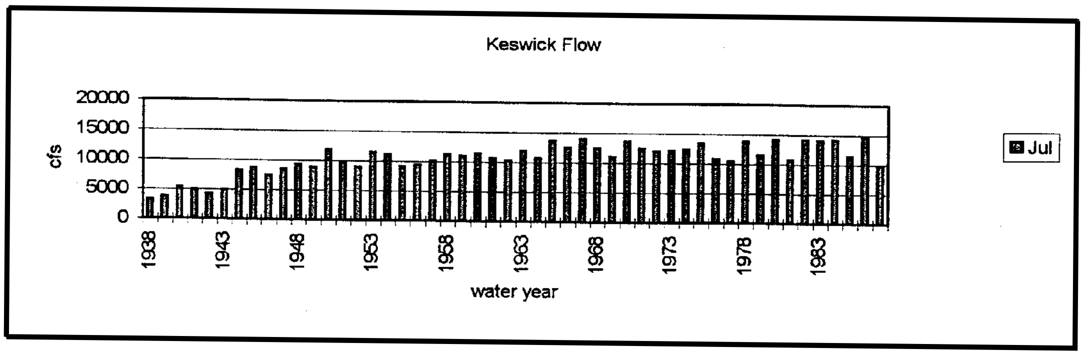
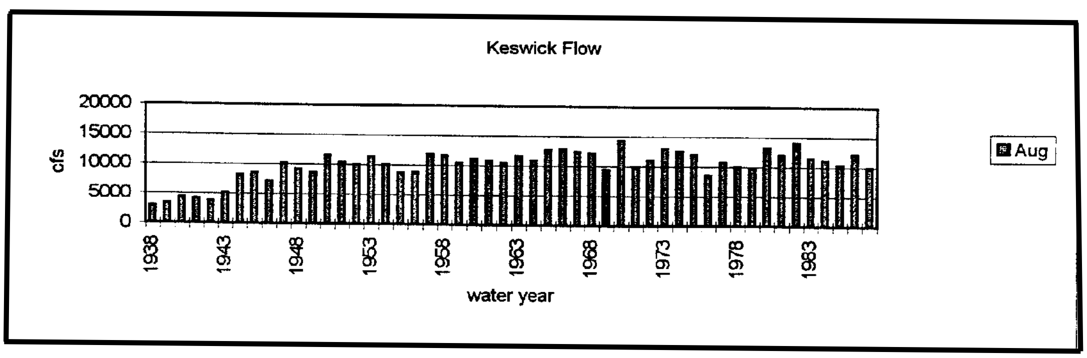


Figure II-2 continued. Average monthly flow of Keswick Dam releases from 1938 to 1987.







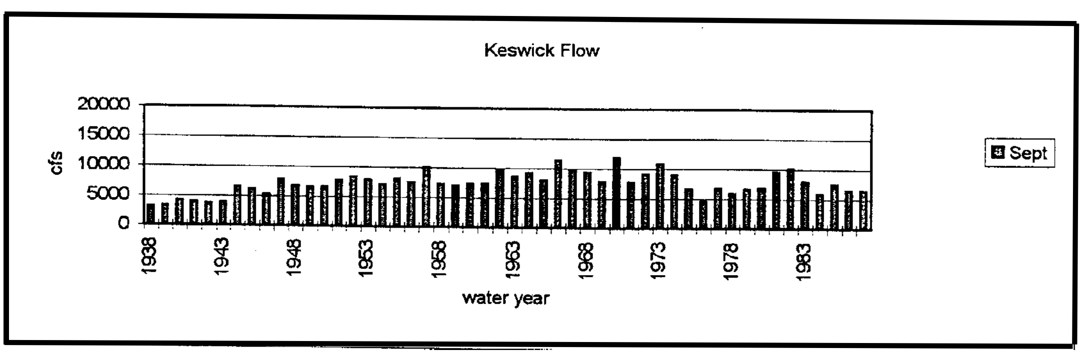


Figure II-3. Monthly average Shasta Dam storage volumes from 1944 to 1993.

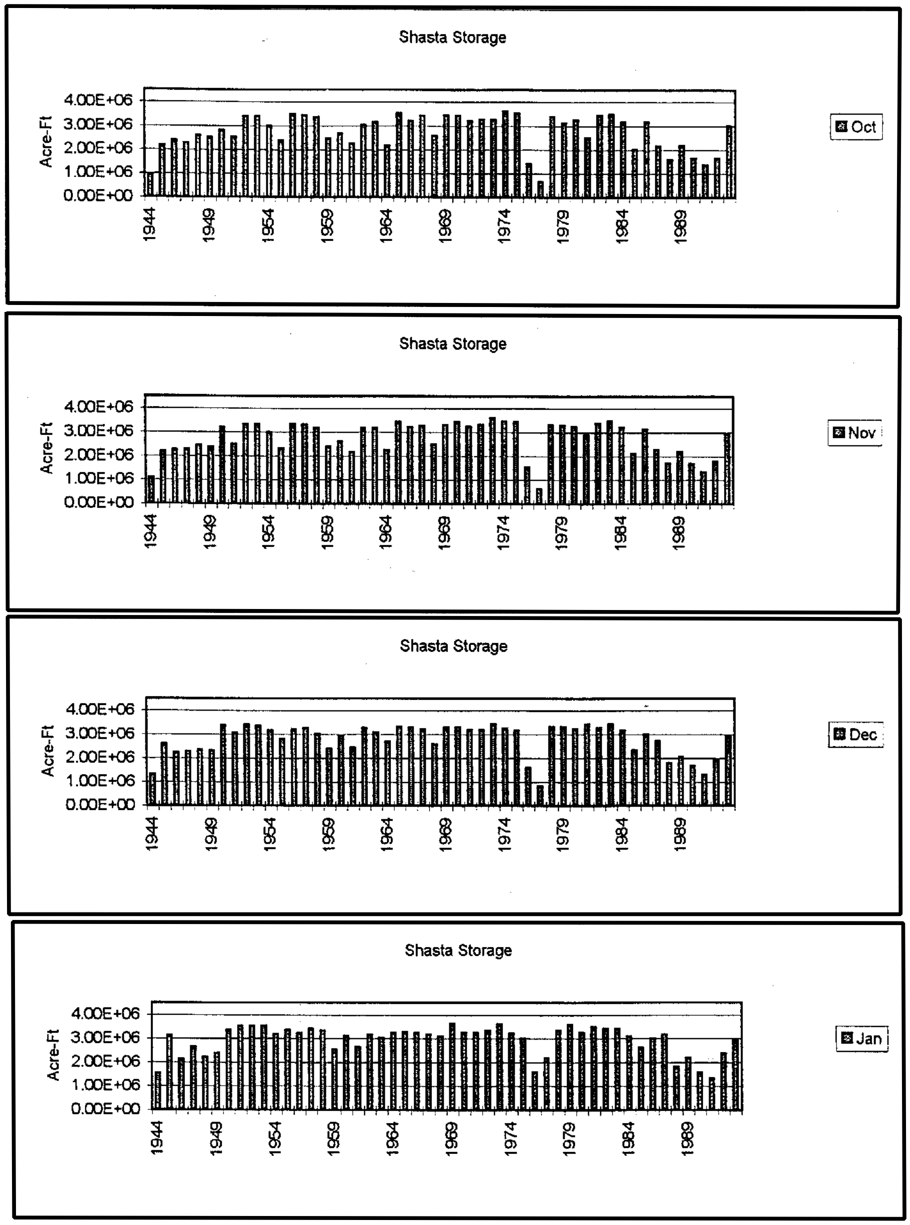
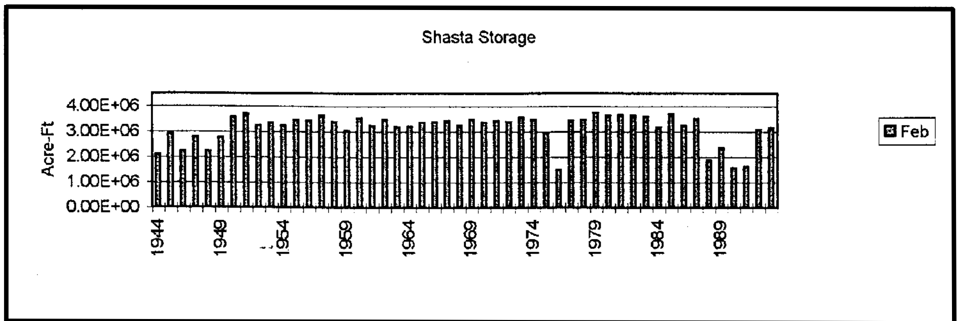
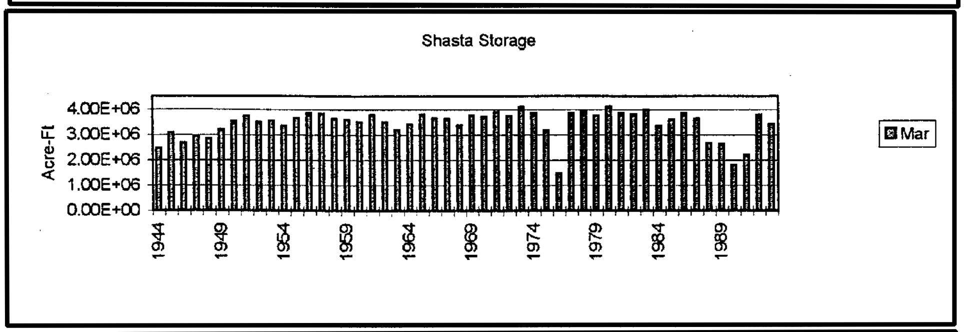
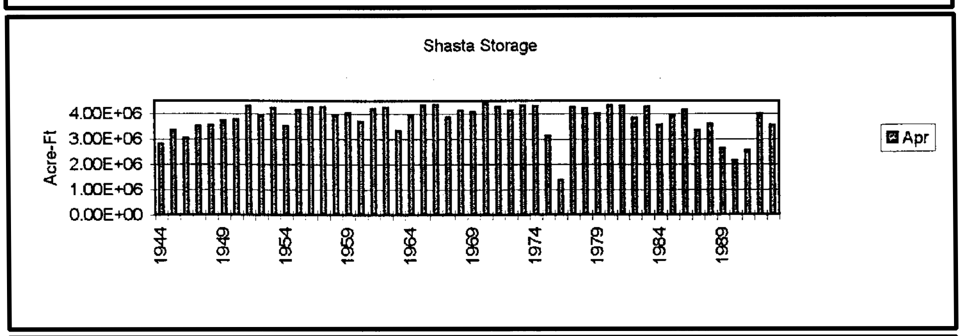


Figure II-3 continued. Monthly average Shasta Dam storage volumes from 1944 to 1993.







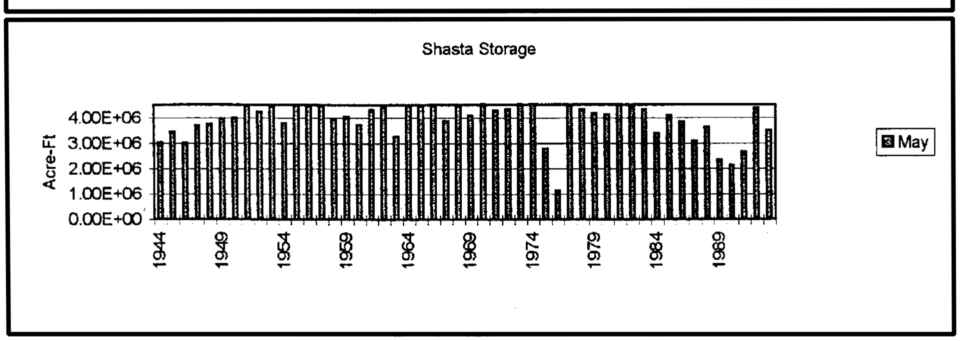
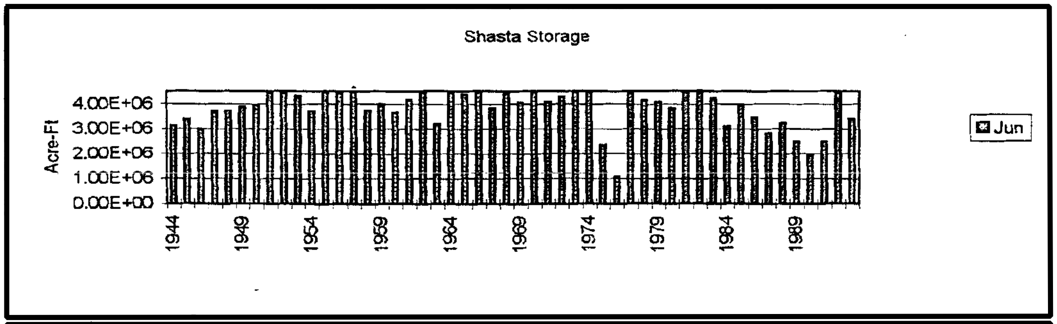
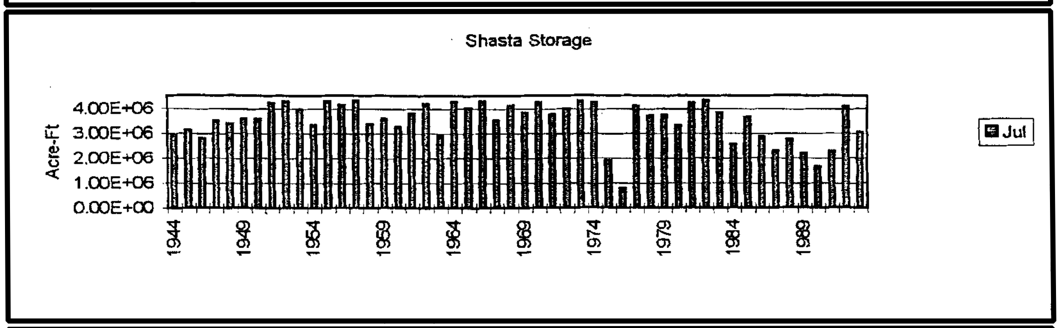
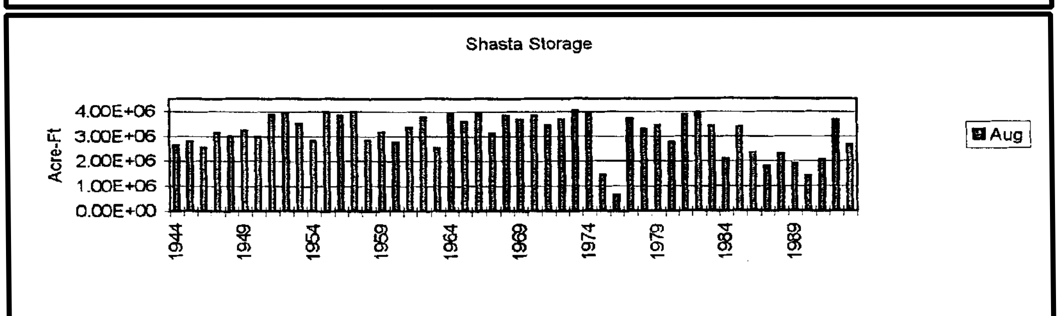


Figure II-3 continued. Monthly average Shasta Dam storage volumes from 1944 to 1993.







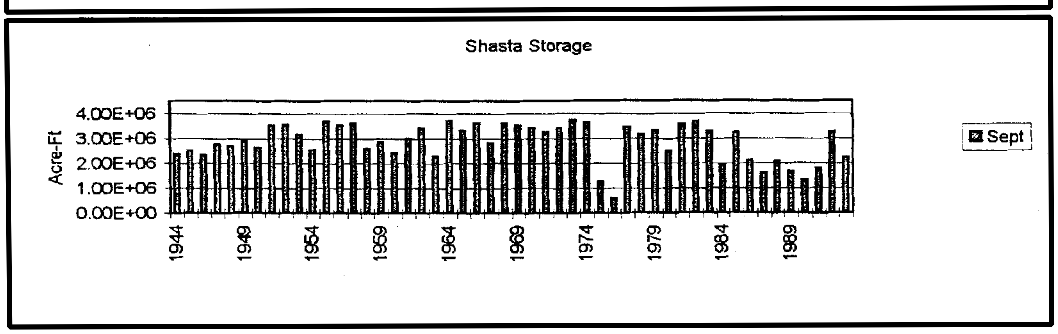


Figure II-4. Monthly maximum temperature at Bend Bridge for various years in which data was available from 1970 to 1989.

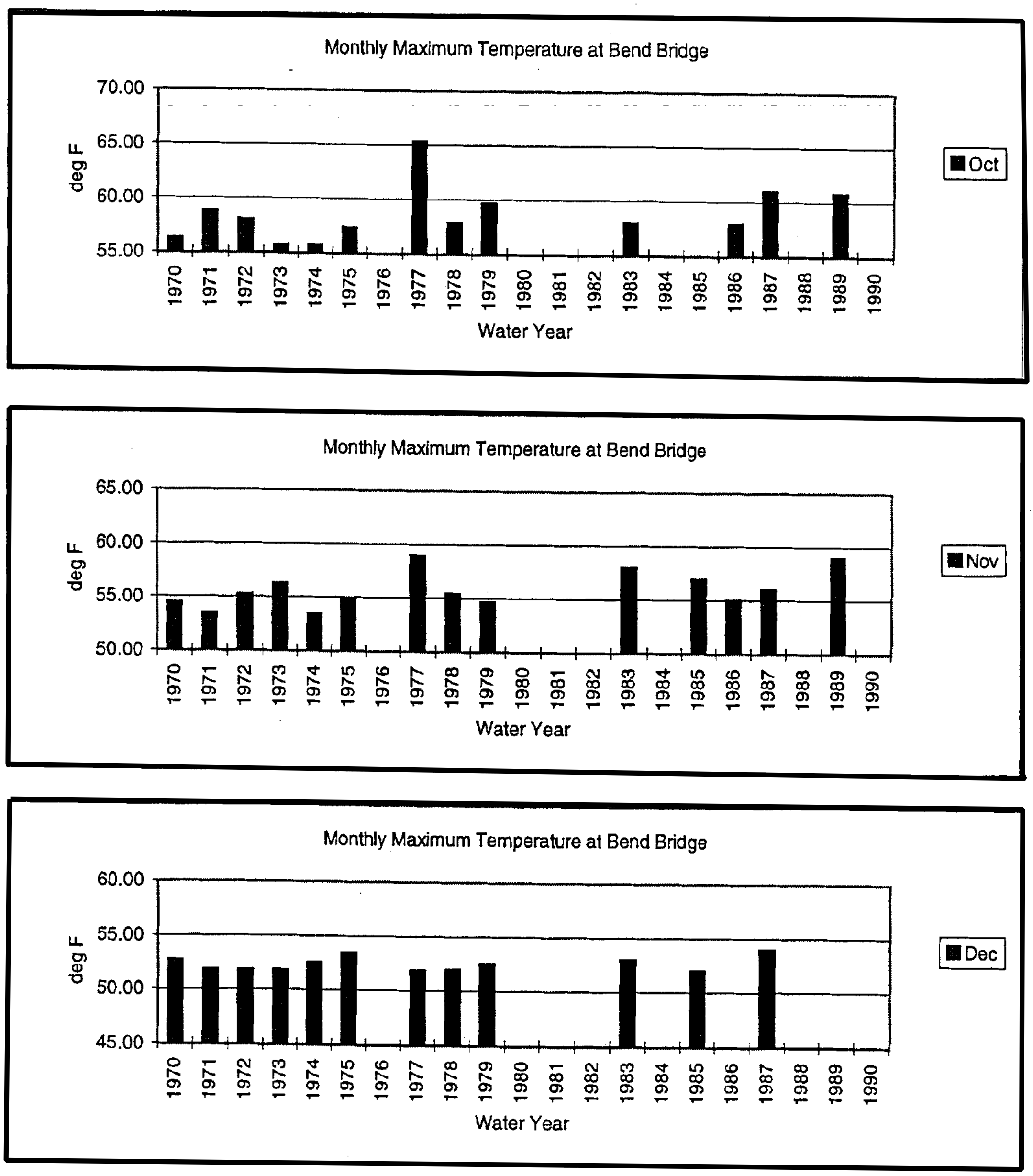


Figure II-4. Continued Monthly maximum temperature at Bend Bridge for various years in which data was available from 1970 to 1989.

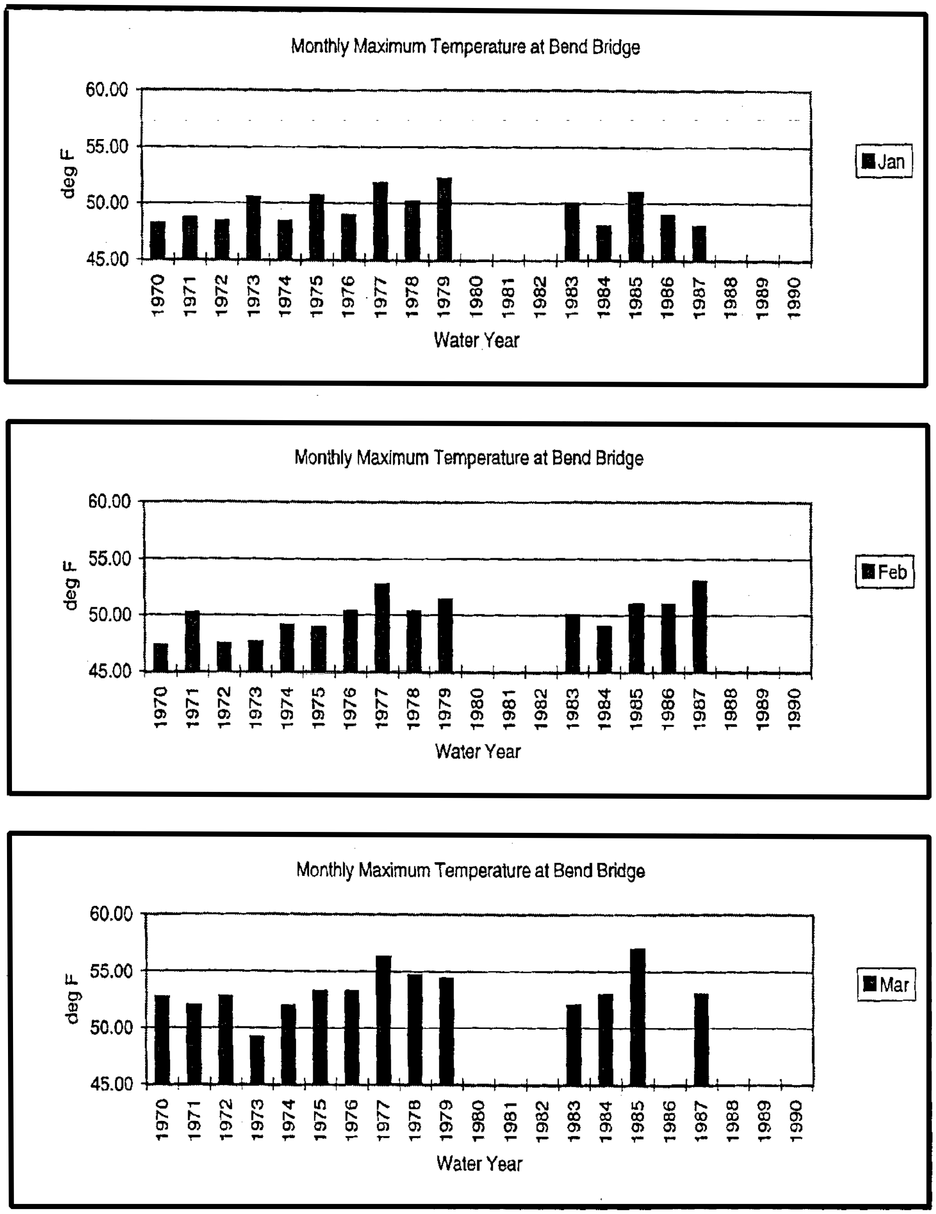
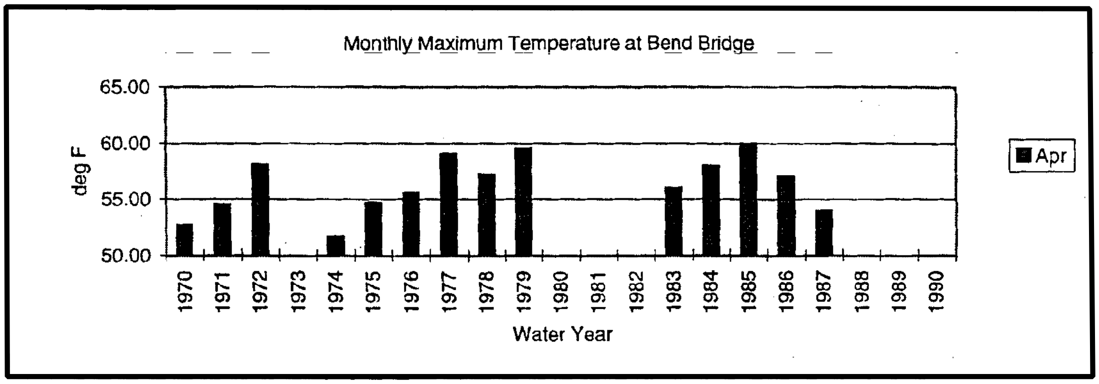
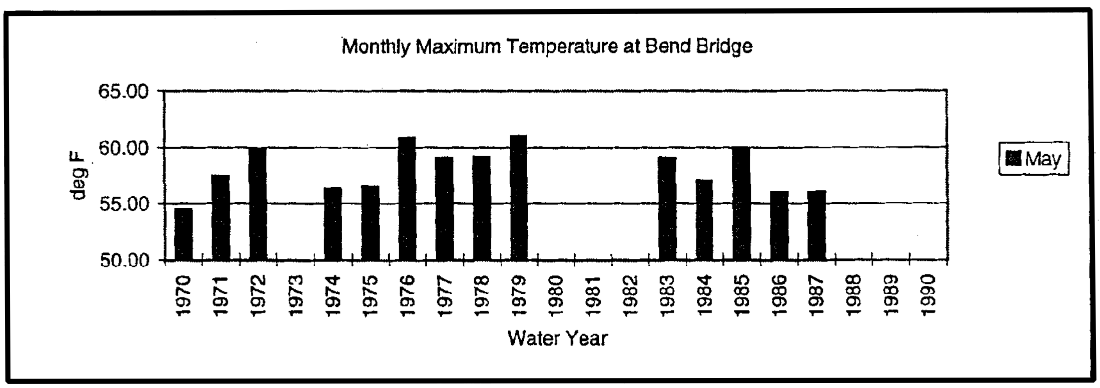


Figure II-4. Continued Monthly maximum temperature at Bend Bridge for various years in which data was available from 1970 to 1989.





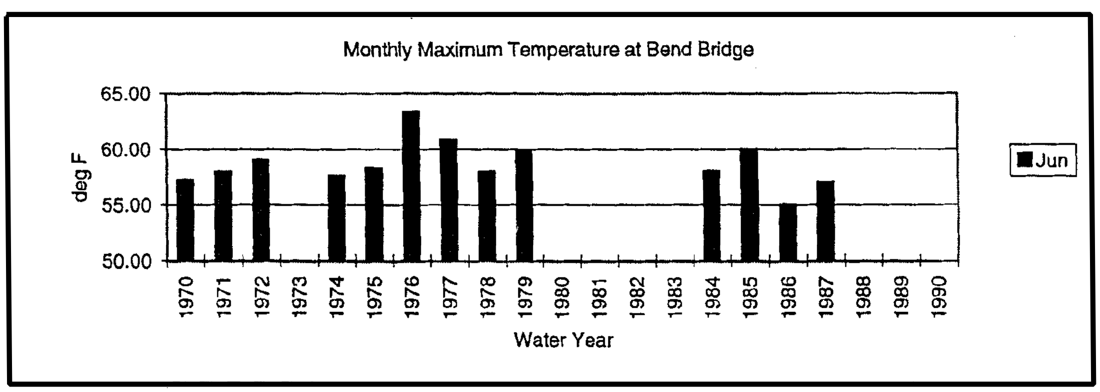
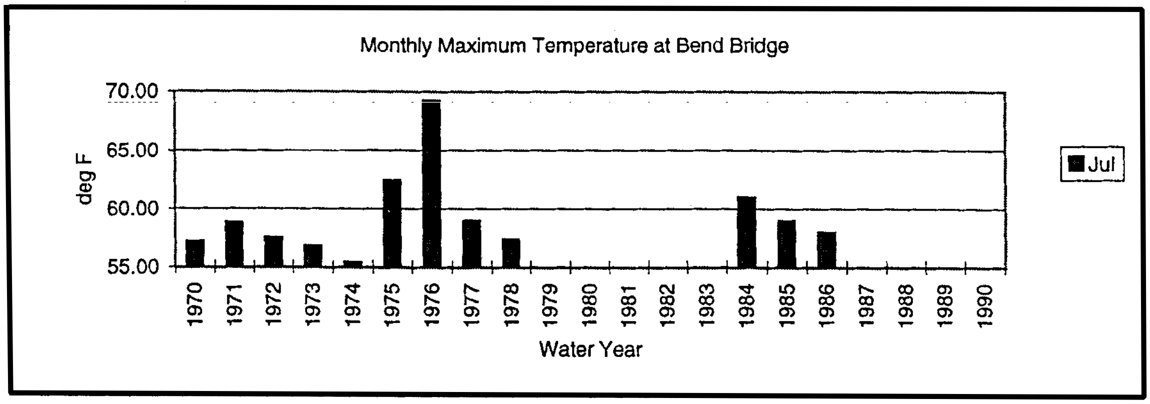
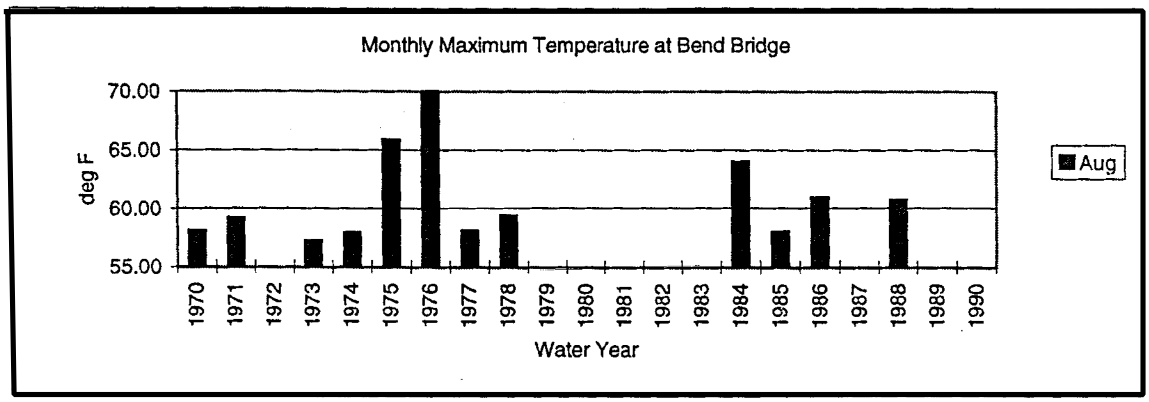


Figure II-4 continued. Monthly maximum temperature at Bend Bridge for various years in which data was available from 1970 to 1989.





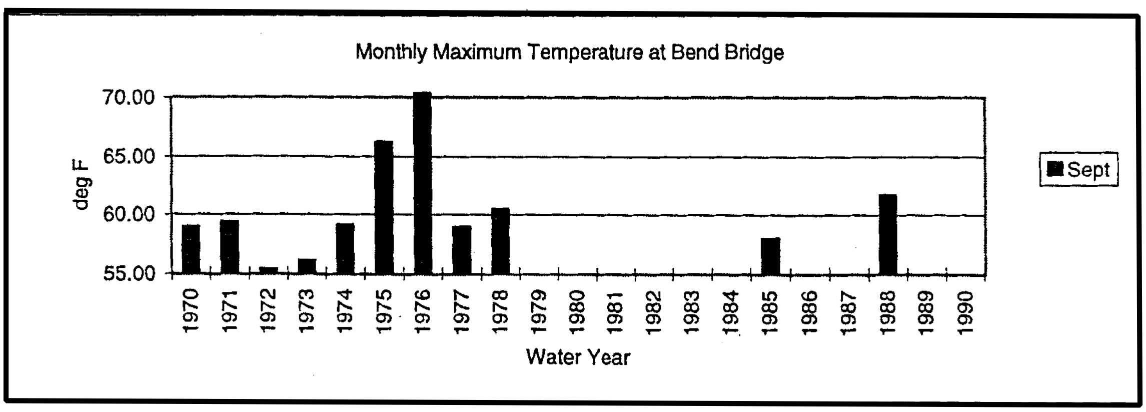


Figure II-5. Sacramento River gill-net landings from 1872 to 1950; and creel census data from in-river sport fishery from 1962 to 1966.

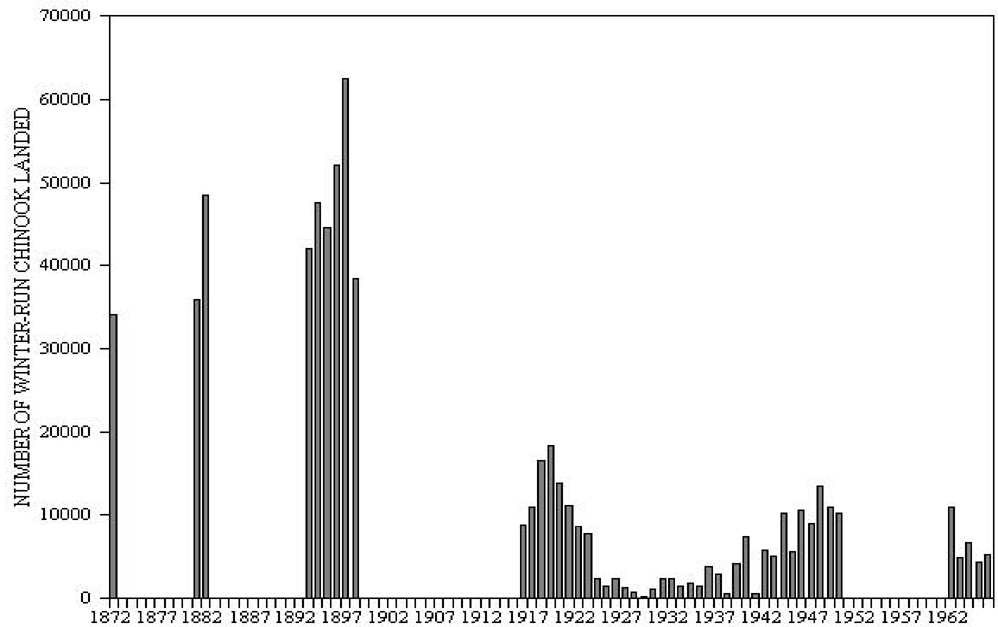


Figure II-6. Commercial salmon catch in the Sacramento and San Joaquin rivers from 1874 to 1957.

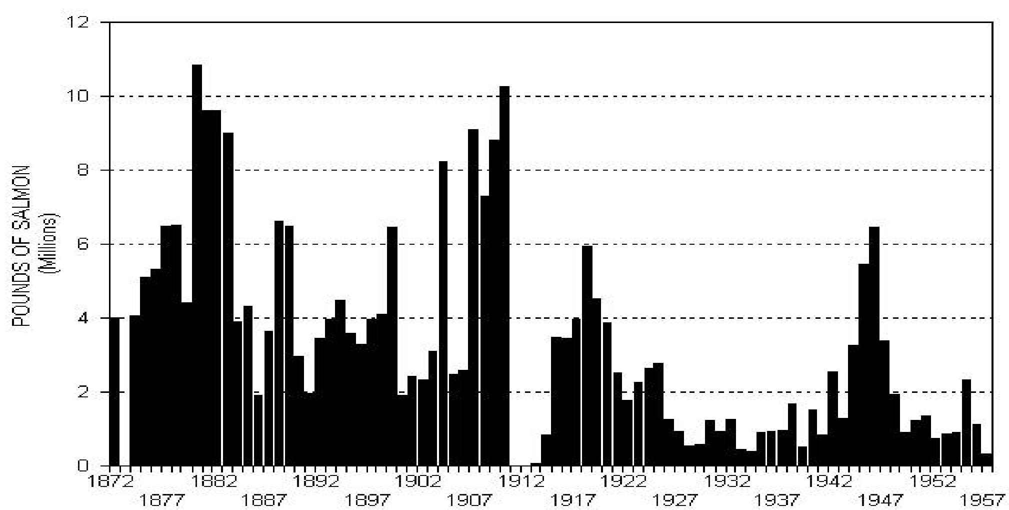


Figure II-7. California commercial salmon fishery, including: in-river harvest from 1916 to 1957; and ocean harvest from 1916 to 1994.

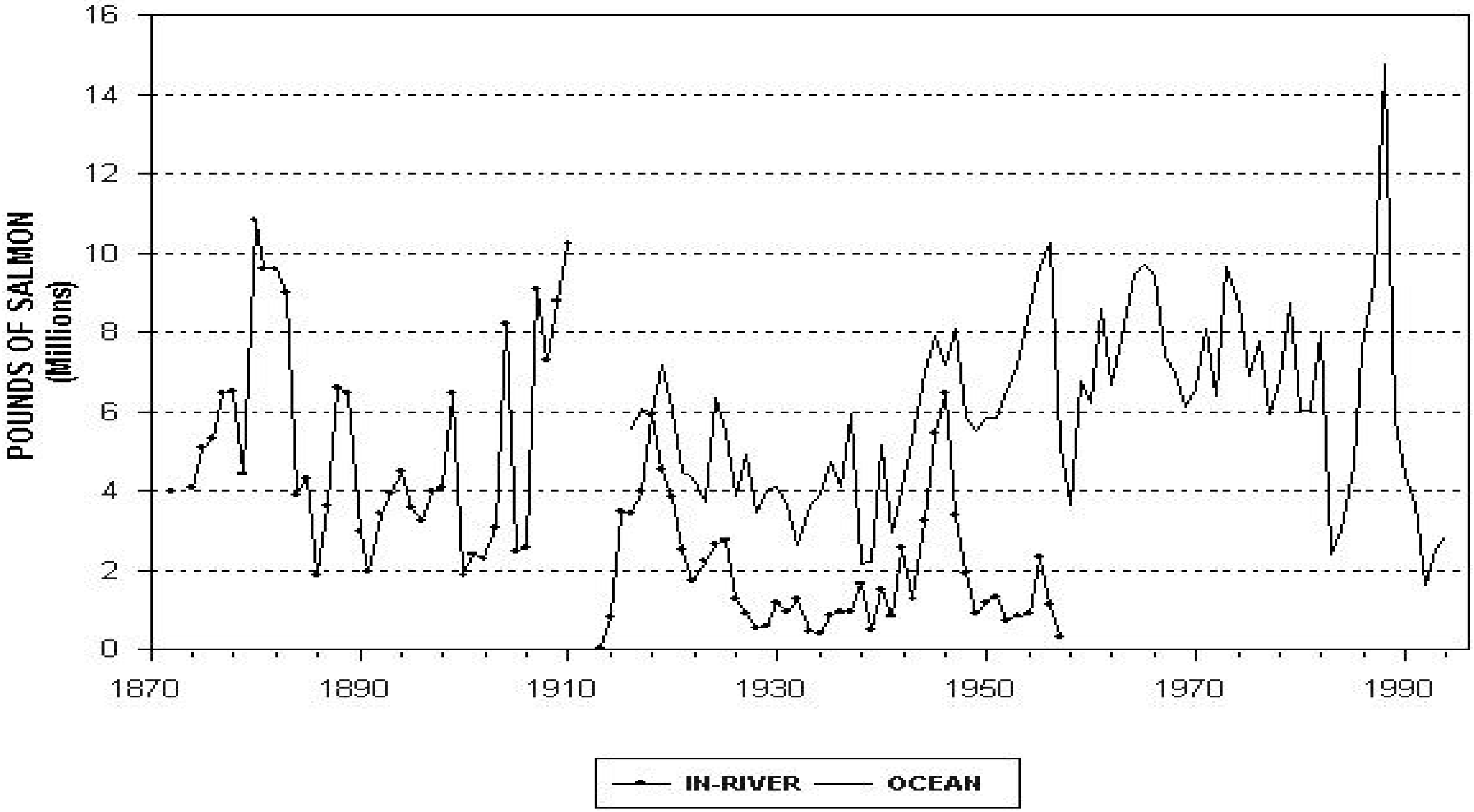


Figure II-8. California ocean recreational landings from 1962 to 1994.

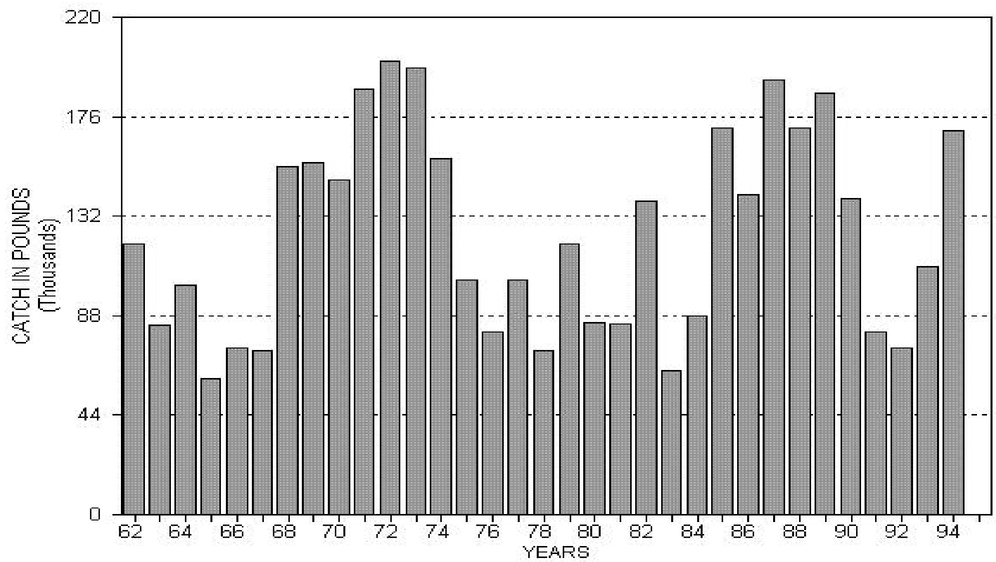


Figure II-9. In-river sport harvest of winter-run chinook salmon upstream of the Red Bluff Diversion Dam from 1967 - 1990.

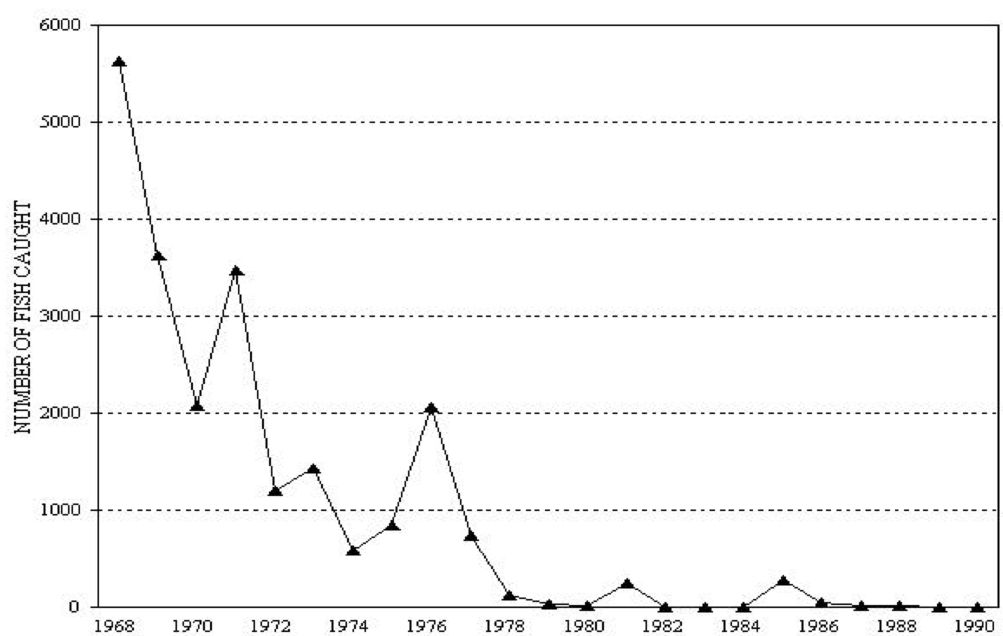


Figure II-10. Plot of Winter-run Chinook Salmon run-size at Red Bluff Diversion Dam.

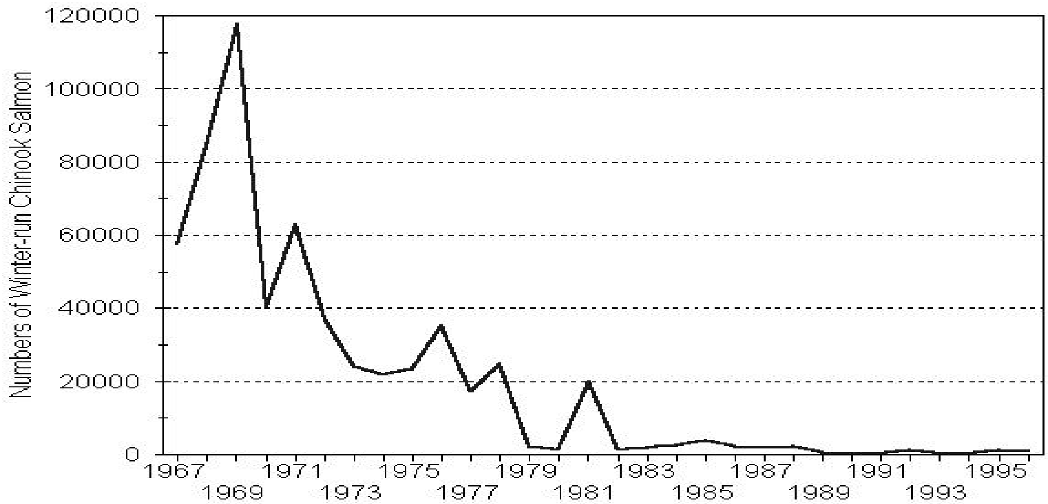
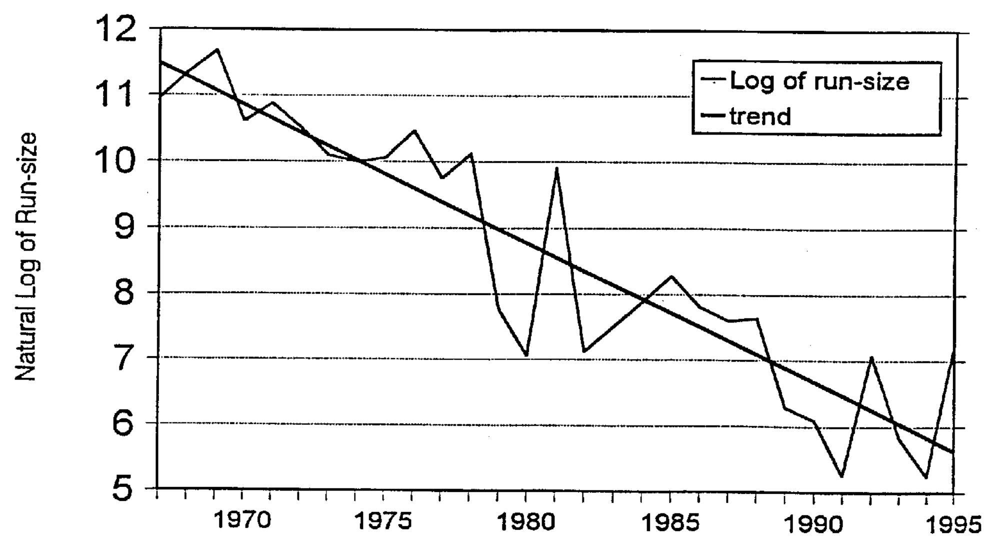


Figure II-11. Plot of the Natural Log of Winter-run Chinook Salmon Run-size at Red Bluff Diversion Dam.



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